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ABSTRACT

This paper presents air quality and ventilation data from an existing chemical laboratory facility and discusses the work practice changes implemented in response to deficiencies in ventilation. General methods for improving air quality in existing laboratories are presented and investigation techniques for characterizing air quality are described. The paper also reviews major design considerations for good indoor air quality in new laboratories; two recently designed projects are used as examples. The program document, used by architects and engineers to design a building according to the requirements of the facility's users, is explained as it relates to indoor air quality. Further discussed is how the program information is translated into design strategies and equipment selection for good indoor air quality. The paper concludes with a summary of conditions which often contribute to poor air quality in laboratories and suggestions for addressing these situations. (GR)

Articles and Publications

INDOOR AIR QUALITY IN CHEMISTRY LABORATORIES

Lecture presented at Pittcon '99, March 10, 1999

by Steve M. Hays, PE, CIH

Abstract

Chemistry laboratories have intrinsically the potential for indoor air quality problems. Research protocols, work practices, and laboratory housekeeping influence air quality. The design and operation of heating, ventilating, and air conditioning (HVAC) systems are the other primary variables affecting indoor air quality.

For a given facility, the interaction of all these variables determines general air quality and occupational exposure of users to airborne contaminants. HVAC design is generally non-variable after building construction is complete, but system operational parameters are variable within some range. Air quality may change significantly as laboratory uses, analytical methodologies, and work practices change. HVAC operational variables may or may not adequately compensate for these changes in what and how chemistry is done.

This paper will present air quality and ventilation data from an existing laboratory facility and discuss the work practice changes implemented in response to deficiencies in ventilation. General methods for improving air quality in existing laboratories will be presented, and investigation techniques for characterizing air quality will be described.

This paper will also review major design considerations for good indoor air quality in new laboratories. Two recently designed projects will be used as examples. A critical part of the design process is programming of the spaces to be designed. Architects and engineers create building designs by working from a program document, which is a statement of the requirements for the facility and the needs of the users. The success of the design effort is directly related to the accuracy of the program. The presenter will explain how the programming effort relates to indoor air quality. From this base, the presenter will discuss the translation of program information into design strategies and equipment selection for good indoor air quality.

The paper will conclude with a summary of conditions which often contribute to poor air quality in laboratories and suggestions for addressing these situations.

Introduction

Indoor air quality (IAQ) is a phrase generally used in reference to the characteristics of indoor air which affect occupants' comfort and health, including gas components, temperature, relative humidity, and contaminant concentrations. IAQ in chemistry laboratories is influenced primarily by 1) the chemistry that is done, 2) the protocols used, 3) the behavior of the users, and 4) the design and operation of building systems, especially heating, ventilating, and air conditioning (HVAC) systems. The interaction of these variables will determine the air quality in laboratories and adjacent spaces. Air inside nearby buildings may also be affected by exhausted air from labs.

Indoor air quality can be poor and have discomforting effects on laboratory users even when airborne chemical concentrations are well below any exposure limits established by regulations. If concentrations of regulated chemicals approach permissible occupational exposure limits, the situation should be considered as a classic industrial hygiene problem. However, many chemical and physical agents without regulated exposure limits are routinely used, and some people are sensitive to airborne chemicals, whether regulated or not, in concentrations near the analytical limit of detection. For example, the author consulted with an organization on an assertion by a researcher of multiple chemical sensitivity caused by exhaust streams from chemistry laboratory hoods located in an adjacent building.

Good air quality promotes the health, comfort, and well being of laboratory users. This paper addresses general air quality. It does not deal directly with exposures above the U.S. Occupational Safety and Health Administration's (OSHA's) permissible exposure limits (PELs); however, application of the information herein to achieve good general air quality will in many situations preclude concerns about "occupational exposures."

Case Study

A university became concerned about the air quality in a thirty-year old chemistry building. Concern was based initially on a visual inspection of the facility by the university's safety professional staff. Many laboratory chemical exhaust hoods were too cluttered to be effective, work practices were often sloppy, and chemical storage in laboratories was generally improper. The initial response was to initiate training for laboratory users and assess the performance of chemical exhaust hoods.

A ventilation test and balance company measured face velocities (F.V.s) for all hoods and relative room pressures in all laboratories. Average face velocities for ninety-nine (99) hoods ranged from 0 to 124 feet per minute (fpm). Room pressures were positive relative to corridors for 14% of rooms tested. Based on these data, hoods were categorized by average face velocity.

Class A (High Toxicity) Usage

- Avg. F.V. = 125 to 150 fpm
- Min. F.V. = 100 to 125 fpm
- Accepted chemical usage: tetraethyl lead, beryllium compounds, metal carbonyls, volatile carcinogens, perchloric acid, etc.

Class B (Normal Laboratory) Usage

- Avg. F.V. = 100 fpm
- Min. F.V. = 80 fpm
- Accepted chemical usage: most materials and operations of average toxicity or hazard

Class C (Low Toxicity) Usage

- Avg. F.V. = 75 to 80 fpm
- Min. F.V. = 50 to 60 fpm
- Accepted chemical usage: materials of low toxicity/hazard: acetone, ethanol, straight chain hydrocarbons, and nuisance dust or fumes.

Since multiple hoods were exhausted by one fan, some hoods were permanently closed to increase velocity for other hoods operating on the same exhaust fan. Velocity was improved in some hoods by installing stops to prevent full opening of the sashes. Repairs were made as needed to replace missing parts, e.g., bypass sashes. After these actions, total numbers of hoods in each category were:

Classification	Number of Hoods
A	1
B	65
C	11
Restricted	3
Closed	19
Total	99

To supplement these air velocity data, work practices were observed in laboratories. The following recommendations were made.

Chemical exhaust hoods should be used in strict accordance with the classification system.

Training in laboratory safety and proper hood use should be given to all laboratory personnel, including professors and graduate students.

A Chemical Hygiene Plan should be put in place.

Air sampling should be done for certain chemicals routinely used in the laboratories to determine the effects of the actions above.

These recommendations were accepted and followed. An air-sampling plan was developed based on observations of laboratory work practices, chemical inventories, and chemicals anticipated to be in use during the sampling time. Target chemicals were:

Chlorinated Solvents

- Chloroform
- Methylene Chloride
- Ethylene Dichloride

1,1,1, - Trichlorethane

Ketones

- Acetone
- Methyl Isobutyl Ketone

Benzene & Derivatives

- Toluene
- Benzene
- Xylene

Additional Contaminants/Sampling Procedures

- Tetrahydrofuran (THF)
- Diethyl Ether
- Broad Spectrum GC/MS sample in Storage Room

All measured concentrations were less than the corresponding Occupational Safety and Health Administration (OSHA) permissible exposure limit (PEL), time weighted average, and the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV), time weighted average, by at least a factor of 40, or the results were reported at or below the limit of detection for the method. The measurements were made over three consecutive days. For the time period of this study, it appeared that the actions taken were effective. It was noted that maintaining good air quality was dependant on continuing proper laboratory protocols and using hoods according to the classification scheme. Any deviations could result in exposures above regulatory limits.

Design Considerations for New Facilities

Successful architectural and engineering design of any facility is directly dependent on the quality of the design program. Laboratories are often complex facilities, requiring special knowledge to develop an accurate program. For building designers, a proper laboratory "program" is a document, comprised of text, tables, and drawings, which sets forth in detail the users' requirements for the facility. Examples of information which should be included are descriptions of tasks to be performed (i.e., experimental and analytical tasks and corresponding use patterns), space requirements and relationships, and flexibility needs. Relative to indoor air quality, it is important that the program address chemicals to be used and ventilation requirements, along with health, safety, and environmental concerns. Programs are sometimes developed internally by users, and someti s professionals are retained to prepare the program. From the program, architects and engineers develop the building design.

Information for programming is developed from interviews with future building users. Examples follow of interview questions related to indoor air.

> What are the analytical tasks to be performed in each laboratory space (include moderately detailed descriptions of each)?
>
> How is each analytical task performed, what is its frequency, and how does it relate to other tasks (i.e., analytical methodologies and use patterns)?
>
> What existing equipment and instruments will be installed in the new laboratory spaces?
>
> What equipment and instruments are anticipated for purchase at occupancy?
>
> What equipment and instruments are anticipated for purchase after occupancy?
>
> What are anticipated changes with time in laboratory tasks and in analytical methodologies?
>
> What are HVAC performance requirements as related to laboratory analytical tasks?
>
> What are exhaust (hood and otherwise) requirements for each laboratory space?
>
> What are the storage philosophy and storage requirements for each laboratory?

It is evident that programs, when developed by external consultants, are best done by persons knowledgeable in science, but who also understand building design (e.g., scientists who work in an architectural and engineering firm). The programmers should understand science well enough to discuss laboratory protocols with the users and politely challenge users to be sure that all operational options that would affect building design are explored. The programmers then should present their findings in a context that is useful to the designers.

The design variables that most influence air quality are the HVAC systems (including chemical exhaust hoods), floor plan, storage systems (chemical receiving, bulk storage, distribution, and in-laboratory storage; waste collection and disposal), and equipment. A brief overview of some HVAC design options is given below.

In addition to comfort control, the HVAC system must serve two primary functions related to general indoor air quality and protection of lab users. Proper pressurization of all spaces must be maintained. Laboratories are usually negative relative to non-lab spaces, e.g., corridors and offices. However, some analytical areas, such as clean rooms, are at positive relative pressure, and biohazard spaces are usually more negative than wet chemistry labs. The ventilation part of the HVAC system must maintain exhaust hood face velocities sufficient to protect the users (100 fpm is a recommended minimum), regardless of sash position. These functions are addressed by the Occupational Safety and Health Administration (OSHA) regulation, Occupational Exposure to Hazardous Chemicals in Laboratories (29 CFR 1910.1450) and the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard, Ventilation for Acceptable Indoor Air Quality (ANSI/ASHRAE 62-1989).

Maintaining acceptable temperature, humidity, and pressure is a major design challenge and requires expensive equipment and complex control systems. Constant volume systems, which deliver constant quantities of air to lab spaces, are sometimes sufficient for simple facilities with small numbers of hoods which operate continuously during working hours. These systems are relatively easy to operate and maintain; however, they are less energy efficient than a more complex system like the one described immediately below.

Variable air volume systems are generally considered the best for laboratories because they provide the best control of pressurization and ventilation with good energy efficiency. These systems vary the quantity of supply air to each space as a function of the exhaust requirements with time. If a hood is turned on or off, the supply air is adjusted accordingly to keep the space at the corrective relative pressure. The systems are often very sophisticated and complex to operate and maintain.

A critical piece of the indoor air equation is the chemical exhaust hood. To prevent occupational exposures to users, hoods must function according to the minimum regulatory standards established by OSHA (see citation above). To also provide good general indoor air quality, the hoods should meet the standards recommended by ASHRAE (see citation above). Four of the most common types of hoods are:

1. Standard - constant volume air flow, variable face velocity,

2. Variable Volume - variable volume air flow, constant face velocity,

3. Bypass - constant volume air flow, constant face velocity,

4. Auxiliary Air - constant volume air flow, constant face velocity.

In addition to types of hoods, there are design options for the exhaust ventilation systems that are connected to the hoods. Each hood can have its own exhaust fan and stack, several hoods can be connected via a manifold to one exhaust fan, and hoods can be exhausted by an in-line fan to a plenum, which is in turn exhausted by another fan to the outside. Regardless of the system, good air quality depends on air handling and control equipment sufficient to maintain the correct room relative pressures and hood face velocities. It is beyond the scope of this paper to describe HVAC and exhaust hood design criteria in more detail; however, these systems are crucial to IAQ, and laboratory functional issues that will impact HVAC and hoods should be addressed at the initial programming phase.

Finally, laboratory design for good IAQ should include a commissioning plan. Building commissioning is an organized and well-planned process designed to verify that all systems are working according to design specifications. Commissioning occurs after construction is complete and before occupancy. Air handling systems are checked for appropriate balance. Building operations and maintenance personnel are given hands-on training, and all systems are tested across their normal and emergency operational ranges. If done thoroughly, this process can require two weeks. The HVAC systems are operated throughout this period. New building finishes and furnishings, which will normally off-gas volatile organic compounds after installation, cure during this time so that most VOCs are exhausted before occupancy. This process can make dramatic improvements in IAQ at occupancy and avoid many problems associated with new facilities. See resource number 1 for more information.

Example; New Facility

A crime laboratory was designed in 1997-98 for a state bureau of investigation. Design for good IAQ was an integral part of the process from the beginning. The HVAC system is a variable air volume type.

Chemical exhaust hoods are controlled by an "In Use" switch. When the switch is activated, a variable air volume box opens supply air in the laboratory to its maximum flow. When hoods are not in use, the supply air closes to a minimum flow, which is determined by space comfort and minimum ventilation requirements.

Laboratory room negative pressure is maintained by airflow measuring devices installed in the supply air, hood exhaust, and return air ductwork. A differential is monitored and maintained so that the quantity of air supplied into the room is less than that of air leaving the room through hood exhaust.

Example; New Lab Space in Existing Office Space Shell

A university converted existing space to a receiving area, with associated laboratories, for chemical, biohazard, and low-level radioactive wastes. HVAC design was especially difficult because of physical space limitations and long duct runs required for exhaust systems. Construction costs were estimated in the early design phase to be over budget. The program was reconsidered in light of these difficulties, and it was decided to eliminate one service function from the space because maintaining acceptable air quality was too expensive if that function remained. This demonstrates the importance of thorough programming and the impact the program can have on ventilation for laboratories, and hence on air quality. (The initial program for this project was developed internally.)

Summary

> Existing laboratories with indoor air quality concerns can be successfully investigated and problems corrected. Initiating proper laboratory work practices and modifying improperly functioning ventilation systems were the major corrective actions for the case study presented.
>
> It is critical to develop thorough and accurate building programs to insure good air quality when designing new laboratory facilities and converting existing spaces to labs.

Many design options are available for laboratory HVAC systems. Selection of systems is critical to air quality, and systems must maintain correct relative room pressures and adequate exhaust hood face velocities.

Investigation of air quality problems in laboratories can include face velocity measurements of chemical exhaust hoods, room pressure measurements, and air sampling for chemicals of concern. Observation of work practices is also very important.

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